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OEE ENHANCEMENT USING TPM IN LIGHT MACHINE SHOP: A CASE STUDY

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Abstract
The exploration for improving productivity in the current global competitive environment has necessitated for rigorously defined performance measurement system in a manufacturing process. In this paper, Overall equipment effectiveness (OEE), an important measure of Total productive maintenance (TPM), has also been calculated to evaluate performance and productivity of the machine. One way to improve productivity is to utilize equipment as effectively as possible. OEE is a well-known measurement method, which combines availability, performance and quality, for the evaluation of equipment effectiveness in manufacturing industry. A case study on broaching machine from one of manufacturing enterprise in India has been done for OEE calculation. The data has been taken for fifteen working days and a multidiscipline team is formed from different department to eliminate any boundaries between the departments and make the maintenance process more effective. With the proper practice of TPM strategy the three factors quality, availability and performance of OEE increased to 99.03%, 85.03% and 83.13% respectively. A set of techniques has also been suggested to the industry after calculating the OEE to improve their OEE from 58.79% to 70.08%. The results has also been compared with world class level, results of the research demonstrate that although the factors of the OEE evaluated on the broaching machine is not reaching world class level however, with the continuous improvement, performance of the machine may be enhanced up to the level.

Keywords: OEE, TPM, Quality, Availability, Performance**.**

INTRODUCTION

It is certain that a nation's economic wealth and growth are dependent on the prosperity of its industrial sector. However, as a consequence of globalization, the manufacturing industry is constantly under high pressure due to increase in competitions. In order to maintain and to develop their ability to compete on scale of global market, manufacturing companies must be successful development for innovative and high-quality products with minimum times, as well as in designing of robust and flexible production systems providing the efficient preconditions for operational excellence [1]. Due to the overall challenges, manufacturing companies must continuously improve the performance of their production systems in order to reduce production costs. This is driven by the customer's demand for annual decreases in product prices and increasing cost competition as products gradually grow into the maturity phase of the product life cycle. Manufacturing output in terms of quality, cost, dependability and flexibility are defined as performance objectives [2] and [3]. Accordingly, the production system must be designed and operated in the flexible manner so that the performance objectives may always be fulfilled. If they are not, the gap between the market requirements and the production performance of any manufacturing company will result in lost competitiveness and hence lost market share and profitability [4]. On a height above that, the production approach should consist of long-term considerations that how to develop the potential of the production system and assets in association with the corporate and business strategy. The rising focus on financial, ecological and social sustainability, more scope is added to the difficulty of designing and operating a production system in a more efficient way. "Lean and green manufacturing" is a term some researchers and companies have adopted to describe both the goals and means related to resource efficiency within manufacturing [5] and [6]. In current manufacturing environment scenario, employing high technology, expensive machines/equipments assisted by computer control and advanced manufacturing concepts, there is almost no place for breakdown of any type. Thus maintenance management is now under an all-time high pressure, with the only goal/aim of "zero breakdowns". Thus starting with conventional repair/maintenance strategy for machines, maintenance has now reached a stage of "Total Productive Maintenance (TPM)" a concept with the aim/goal of "zero down time". Today many companies have shifted their attention to optimize their assets, and use equipment's in quite more effective manner. The main part of the company which puts a strong influence on the assets is the department of maintenance or the employees responsible for the maintenance. The concept of maintenance management which already been developed and successfully implemented world class manufacturing strategy is an innovative, non-traditional approach to plant maintenance and is complementary with Total Quality Management (TQM), Just In Time (JIT), Total Employee Involvement (TEI) and Continuous Performance Improvement (CPI). The work of any machines is high productivity and efficiency, and the maintenance is the responsibility of employee and its focus to prevent the problem before its occurrence. TPM literature shows that two main approaches in order to define TPM exist and the Western approach in addition to the Japanese approach [8], with significant similarity within the two. Various researches describes the Japanese school of thought [8]-[11], [14], [15] and [18]. The Japanese Institute for Plant Maintenance (JIPM) strengthens on the Japanese approach of Siiechi Nakajima who is the vice chairman of JIPM and is supposed to be considered as the father of TPM. According to Nakajima's Japanese statement of TPM is:

TPM aims to maximize the equipment effectiveness.

TPM creates a thorough system for the Preventive Maintenance (PM) of the equipment's throughout the entire life span.

TPM is basically a cross-functional, implemented by many departments (engineering, operators, maintenance, and managers as well).

TPM involves every single employee of organization.

TPM is extension/ promotion of PM through the motivation of management and autonomous small group activity.

The Western approach is closely related and supports the definition of Nakajima (Japanese Approach) but give his own definition that favors the teamwork but does not essentially require total employee involvement Willmott [14]. Importance is on the use of teams to reach specific equipped goals. "The philosophy at the heart of the TPM process is that all the assets on which production depends are kept always in optimum condition and available for maximum output." Hartmann [16] presents a similar definition to Willmott i.e., "Total Productive Maintenance lastingly improves the overall efficiency of equipment with the active involvement of their operators".

Basically TPM is the new maintenance strategy developed in order to gather up the new needs of maintenance. TPM is an American style for industrious maintenance which has been superior and adapted to fit in the Japanese industrial environment. Now it is accepted in Japanese industry and in additional western countries as well. The following definition may be used to describe the Total Productive Maintenance. *Total Productive Manufacturing is the ordered equipment-centric nonstop enhancement process which strives in order to optimize the production effectiveness by identifying, eliminating losses of equipment and efficiency all through the production system life cycle by energetic team based involvement of employees across all levels of the operational chain of command* [17]. During 1980's, Total productive maintenance (TPM) has become known in manufacturing industries and Overall equipment effectiveness (OEE) was proposed by Nakajima [9] to evaluate the progress of TPM. It is interpreted as the multiplication of availability, performance and quality. Various researchers have worked on OEE. [18]-[22] and [25].

I. OVERALL EQUIPMENT EFFECTIVENESS (OEE)

In mechanized environments it was long held that there should to be a exchange between quality and output. Production may scream at engineering that they required more "up time", while engineering complained of production that there was never much time to do appropriate maintenance. When quality matters arise production would guilt poor maintenance that in turn would set up additional maintenance checks which compact up-time and hence output. This skeptical view is due to the lack of a single measure that united engineering and production objectives. The good feature of OEE is the way it achieves this, by selling with three significant factors, each of which has the capability to badly impact on customer service and cost.

OEE is a chain of command of metrics presented by Nakajima [9] to compute the performance of the tools in a factory. OEE is a really foremost tool that can be used also to achieve diagnostics as well as to estimate production units in differing industries. The OEE has bear as the spine of TPM and then of other techniques incorporated in asset management programs, tip manufacturing, six sigma and world class manufacturing. OEE is the simple tool that will facilitate manager to measure the efficiency of their tools. It takes the most common and significant sources of productivity loss, which are called six big losses and given in Table 1.

A. OEE Calculation

OEE is equal to the product of the three main factors for the major six big losses

1. Availability indicates the problem which caused by downtime losses.
2. Performance indicates the losses caused by speed losses and
3. Quality indicates the scrap and rework losses

TABLE1: SIX BIG LOSSES ADDRESSED BY OEE

Six Major Loss Category	OEE Factor	OEE Loss Category
Breakdowns	Availability	1. Equipment failure 2. Major component failure 3. Unplanned maintenance
Set up and adjustments	Availability	1. Equipment setup 2. Raw material shortage 3. Operator shortage
Minor stops	Performance	1. Equipment failure < 5mins 2. Fallen product 3. Obstruction blockages
Speed loss	Performance	1. Running lower than rated speed 2. Untrained operator not able to run at nominal speed 3. Machine idling
Production rejects	Quality	1. Scrap 2. Rework 3. In process damage
Rejects on start up	Quality	1. Scrap 2. Rework 3. In process damage

B. OEE Calculation

OEE is equal to the product of the three main factors for the major six big losses

1. Availability indicates the problem which caused by downtime losses.
2. Performance indicates the losses caused by speed losses and
3. Quality indicates the scrap and rework losses

$$OEE = Availability \times performance\ rate \times Quality\ rate \ldots (1)$$

C. Availability

The availability is normally calculated as the ratio of difference of required availability and downtime to the required availability. This may be written in the form of formula:

$$availablility = \frac{Required\ availablility - Downtime}{Required\ availablility} \qquad (2)$$

The required availability may be defined as the difference of time of manufacture to function the equipment with the other intended downtime like breaks, meetings etc. The down time might be given as the real time in which the equipment is losing for maintenance work or changeovers. This time may be known as the break down time. The result of this formula gives the true availability of the equipment. The value may be used in the OEE formula to measure the effectiveness of the equipment.

D. Performance Rate

The performance rate may be defined as the design cycle time in order to produce the item multiplied by the output of the concerned tools and then the complete is divided by the operating time. This will lead to the performance rate of the equipment. The value may be used in the overall equipment effectiveness formula in order to measure the effectiveness of the equipment.

$$performance\ rate = \frac{Design\ cycle\ time - output}{Operating\ time} \qquad (3)$$

The design cycle time which is also known as the production output will be in the unit of production, like parts in one hour and the output would be the total output in the given time frame. The operating time would be the availability value of the availability formula. The result of the above formula would be in the percentage of the performance of the equipment.

E. Quality Rate

The quality rate may be defined as the ratio of difference between production input into the process or equipment and the number of eminence defects to the manufacture input. The quality rate may be expressed in a formula as

$$Quality\ rate = \frac{Production\ input - quality\ defects}{Production\ input} \qquad (4)$$

The production input indicates the unit of product being feed into the production process. The quality defects stand for the amount of products which are below the quality standards this formula may be very helpful to calculate the quality problems in the production process.

E. Illustrative Study

Power plant equipment manufacturer has been taken as case study this company is applying high level of quality & reliability of goods and systems is the product of strict devotion to international standards by acquiring and adapting few of the best technologies from top Original equipment manufacturer (OEM) companies in the world jointly with technologies produced in their own R&D centers. Most of our manufacturing units and other entities have been recognized to Quality Management Systems (ISO 9001:2008), Environmental Management Systems (ISO Systems (OHSAS 18001:2007).

The study conducted along couple of years ago in the company that produces different types of turbines, turbo generators, heavy castings and forgings, control panels, light aircrafts and electrical machines. In the industry the production is continuous there is only two manufacturing units namely heavy electrical equipment plant (HEEP) and central foundry forge plant (CFFP).

The study is conducted on broaching machine-I (shown in fig. 1) located in bay 3 of LMS section of HEEP unit as most frequency of failure (1.2/shift/month) probably occurred in the broaching machine-I and also for the following reasons it is classified as high value items (A-class), one of most expensive machines, low performance efficiency, high maintenance cost and small improvement in availability may lead to high profit to industry for that the average time loses that are observed in the production process in the month of October-November 2015 is recorded and shown in table 2.

TABLE 2: OVERALL EQUIPMENT EFFECTIVENESS AS MANUFACTURING PLANT BEFORE TPM IMPLEMENTATION

Abbreviations	OEE Factors	Time/number
	Availability	
A	Total available time (general shift)	450 minutes
B	Planned down time	60 minutes
C	Loading time (A-B)	390 minutes
D	Unplanned downtime	78 minutes
E	Actual operating time (C-D)	312 minutes
F	Availability (E/C) = 0.80 (80%)	
	Performance efficiency	
G	Total parts run	180 parts
H	Ideal Cycle Time (no. of components/min.)	0.75 minute/part
I	Expected parts run (H*E)	234 parts
J	Performance Efficiency (G/I) = 0.7692 (76.92%)	
	MIA (Missing in action) time = Actual operating time – Total parts run * ideal cycle time	177 minutes
	Quality Rate	
K	Total defects (rejection)	8 parts
L	Quality rate (G-J)/G = 0.9555 (95.55%)	
Overall Equipment Effectiveness (F*I*L) = 0.5879 (58.79 %)		

Fig. 1: Broaching machine-I (LMS section)

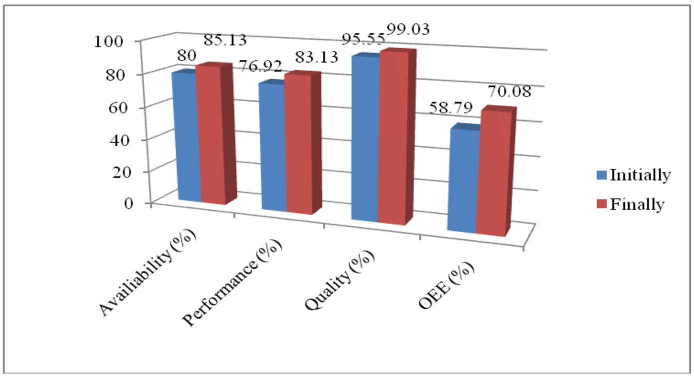

Fig. 2: Graphical reprersentation of OEE and its component

II. IMPLEMENTATION OF TPM STRATEGY:

With the increasing pace of globalization the Indian industry also faced all challenges of adopting cost effective manufacturing strategies. There is emerging need for TPM implementation in the Indian industry and need to develop TPM implementation practice and procedures. The company was being motivated to implement TPM to cope with the new market need and to increase their production performance at the international level, and the desire to eliminate the waste which does not add value for the production like waste of time and waste of material as well. The first initiative was towards the increase of quality, by implementation of good quality on-line inspection system, monitoring and that was through the creation of the quality improvement team which also train employees to identify the problems related to the quality and their causes, and this data is further used for a continuous improvement [22]. Launch autonomous maintenance tasks in the aim to setup and adjust the equipments, inspecting the equipments while cleaning it and checking the machine bolt tightness. The creation of multidisciplinary teams involving all the departments, even the supplier is invited to the meeting to discuss the quality of the raw material supplied. The company has an old record for maintenance of broaching machine provided in tables 3-5.

The primary goal of autonomous maintenance is to prepare operators to do some equipment care independently of the maintenance staff. After setting up of maintenance standards for machine certain *Fuguais* (abnormalities) are observed in machine they are checked these Fuguais are provided in table 6.

As OEE measurement is an effective way of analyzing the efficiency of a single machine. It is a function of availability, performance rate, and quality rate. OEE is calculated for the broaching machine before (table 2) and after (table 7) TPM implementation.

III. RESULTS & DISCUSSIONS

In today's global economy slow and steady improvements in manufacturing operations will not guarantee profitability or survival. As a result, an increasing search is on for methods and processes that drive improvements in quality, costs and productivity. Specific suggestions (Kaizens) are provided in table 7.

In most of Indian manufacturing enterprises they don't have system which calculates their performance while they have standard OEE since the installation of a machine. But without calculating it cannot be improved, it was observed that at present performance of the company as overall equipment effectiveness is 70.08%, where the availability of the machine was 85.13 % of the production time and the performance was 83.13 % while the quality factor is 99.03 %. Table 9 shows the comparison between world class measurement (WCM) and the machine measurement.

The OEE tools were used to calculate the OEE for the broaching machine – I of LMS section. OEE splits the performance of a machine into three separate but measurable components: availability, performance and quality. OEE of machine improves by 11.29 % by applying TPM effectively. Figure 2 shows the comparison of OEE and its components before and after implementing TPM. This study measured the existing performance of the broaching machine – I of LMS section of the selected industry in terms of availability, performance and quality rate by the tool OEE. Among all the three factors of OEE i.e. availability, performance and quality rate, the quality rate was found to be satisfactory. But a lot of progress needed to be made in performance and availability. Especially the availability factor is very poor due to large switch time and breakdown. So, the factors leads to availability losses need to be well-known and eliminated. Some factors that were known are responsible for productivity loss. As we see from the table 9 that the company achieved the world class quality factor, and as company applied a strong quality measurement and check system start from the raw materials list to the work in process ended with finish goods inventory. But the company required to-work hard to pick up their system machines and reduce the waste time.

IV. CONCLUSIONS

On the basis of the theory studied and analyzed, a set of recommendations were suggested in paper in order to improve the OEE thereby increasing the output of the machine. Utilization of machines may only be enhanced and controlled successfully if suitable performance estimation is used. OEE is a known way to compute performance of production equipments and machines in manufacturing in industries and adapted for manufacturing enterprise. It aims to classify unproductive time losses within the system and these time losses influence availability, performance and quality.

By implementing the TPM strategy they can eliminate most of the waste happened like the waste of time during changeover or the downtime losses, with this maintenance strategy the responsibility to maintain the machine depends on

TABLE 3: STANDARDS FOR CLEANING (BROACH MACHINE-I)

Location	Method of Cleaning	Standard	Time	Frequency
Operator Table	Dry cloth	No mist	1 minute	Shift
Pedestal platform	Wire brush	No mist	2 minutes	Week
Machine table	Dry cloth/brush	No chips	2 minutes	Shift
Work head	Dry cloth/brush	No chips/oil	2 minutes	Daily
Machine front	Dry cloth	No oil	1 minute	Shift
Hydraulic tank outside	Dry cloth	No mist	5 minutes	Week
Hydraulic pipe cleaning	Dry cloth	No dust/oil	5 minutes	Week
Machine back	Dry cloth	No oil	2 minutes	Daily
Electric panel	Dry cloth	No dust	2 minutes	Daily
Chips tank	Wet cloth/brush	No mist	2 minutes	Week
Hydraulic valve	Dry cloth	No dust	5 minutes	Week
Electric motor	Dry cloth	No dust	2 minutes	Twice a week

TABLE 4: STANDARDS FOR INSPECTION (BROACHING MACHINE - I

Location	Method of Inspection	Standard	Time (sec)	Frequency	Action if not OK
Hydraulic tank oil level	Visual	Maximum and minimum level	20	Week	Fill oil
Magnetic separator/ chip collector	Visual	Filled to top	10	Daily	Cleaning required
DC valve	Visual	No leakage	15	Daily	Inform maintenance

TABLE 5: STANDARDS FOR LUBRICATION (BROACHING MACHINE - I)

Location	Method of Lubrication	Type of Lubricant	Quantity	Frequency
Slides	Manual	Oil	As per requirement	Week
Oil sump	Manual	Oil	As per requirement	Twice a month

TABLE 6: OVERALL EQUIPMENT EFFECTIVENESS AS MANUFACTURING PLANT AFTER TPM IMPLEMENTATION

Abbreviations	OEE Factors	Time/number
	Availability	
A	Total available time (general shift)	450 minutes
B	Planned down time	60 minutes
C	Loading time (A-B)	390 minutes
D	Unplanned downtime	58 minutes
E	Actual operating time (C-D)	332 minutes
F	Availability (E/C) = 0.8513 (85.13%)	
	Performance efficiency	
G	Total parts run	207 parts
H	Ideal Cycle Time (no. of components/min.)	0.75 minute/part
I	Expected parts run (H*E)	249 parts
J	Performance Efficiency (G/I) = 0.8313 (83.13%)	
	MIA (Missing in action) time = Actual operating time – Total parts run * ideal cycle time	176.75 minutes
	Quality Rate	
K	Total defects (rejection)	2 parts
L	Quality rate (G-J)/G = 0.9903 (99.03%)	
Overall Equipment Effectiveness (F*I*L) = 0.7008 (70.08 %)		

operators and engineering persons, there will be no more fault and the break down will be solved as fast as possible. The operators on the shop floor should be involved in each maintenance operation because they are the one who are close to the machines and knows what the abnormalities of the machines are. The operators are the key persons in the production system. So to get the maximum output with high quality products, it is necessary that they have the good skills as according to their job. So our suggestion is that the company should arrange some training for them time to time to keep them updated and motivated. The maintenance has the direct contact with the production system to keep the production machines as much as possible to the best conditions to minimize the disturbance in the production and as a result the production will be more with high quality. Further, on time delivery to the customer will increase their satisfaction level.

The scope of improvement for the future course is highlighted by the recommendations which were done by a series of brain storming sessions and visiting the shop floor, observing the daily activities of the operators and the works. The other advantage of the maintenance will be appearing in the form to establish a more reliable and stable production system.

The production of the orders and delivery to customers will be on time which will increase the satisfaction level of the customer. This increase in production and the satisfaction of the customers are the benefits for the company to increase the sales of the products and to make the more profits for the company.

TABLE 9: THE COMPARISON BETWEEN WCM AND MACHINE

	OEE Machine	**OEE World Class**
Availability	85.13 %	90 %
Performance	83.13 %	95 %
Quality	99.03 %	99 %

Table 7: Fuguais found in Broaching Machine-I

Fuguai description	**Problem**	**Reason**	**Counter measurement plan**
Leakage from DC valve	Oil wastage	Nut loose	Tight it properly
Screw is open from flow control valve pipe	Oil wastage	Negligence	Tight it properly
Hydraulic oil filter is open	Dust contamination in oil	No maintenance	Fit it at proper place
Leakage found from connection of pipe and hose behind DC valve	Oil wastage	No maintenance	Repair
Leakage found from flow knob	Oil wastage	Negligence	Repair
Two screws are missing from oil pipe seal cap of heat exchanger	Oil wastage	Negligence	Repair
Hydraulic pipes are not cleaned	Looks bad	No Cleaning	Clean it
Standing platform oily	Looks bad	Negligence	Clean properly
Leakage from flow control valve	Oil wastage	Negligence	Repair
Valves behind DC is leaking	Oil wastage	Negligence	Repair
Connector leakage near DC valve	Oil wastage	Negligence	Repair
Machine base found unclean	Looks bad	Negligence	Clean
Oil split out while cleaning	Oil wastage	No cover for machine	Provide cover
Tool table oily	Looks bad	Negligence	Clean it properly
Chips contamination in loose wire connections	Sort circuit can occur	No provision to stop chip scattering	Clean wire connections and cover all connections
Wire clamp broken	Wires come out	No maintenance	Repair
Pipe clamp bolt is missing from right side	Pipes unsafe	Poor workmanship	Repair
Electric wires not covers	Cause trip down	Negligence	Cover all wires
Hydraulic connection loose	Oil leakage and wastage	Negligence	Repair and tight
Electric wires not cover near work head	Bad appearance	Design considerations	Provide cover

Table 8: Kaizens performed on broaching machine – I

Kaizen theme	**Problem**	**Solution**	**Results**	**Benefits**
To provide cover for machine head	Chips and oil split out while working	Design of proper covering system	Splitting of oil and chips is avoided and less cleaning is required	More clean space machine works properly
To provide plastic cover on control panel	Oil can go into the control panel which causes short circuit	Plastic cover should be provided	Panel looks more neat and clean, more safe	Become more safe, less cleaning is required
To change the design of decanting tank	Oil comes with the chip and is not separated	To separate oil and chips in the decanting tank by changing its design	Chips don't get mixed with the oil	Wastage of oil is reduced
To fix filter on its place	Oil becomes contaminated	Fix the filter on its place	Contamination stopped	Clean oil
To replace glass of load panel	Looks bad	Provide glass	Easy to visualize	Looks good
To change the design of coolant nozzle	Difficult to operate	Design a new nozzle	Coolant directly falls on the glass	Wastage of coolant is reduced
To replace the scale of worktable	Not properly visible misjudgment	Replace it	Easy to take readings	
To provide bulb and cover on control panel	Indication is not achieved	Provide bulb and cover	Indication is achieved	
To provide bolts on coolant motor	Improper working	Provide bolts	Motor starts working properly	
To change the head stock scale	Scale numbers are totally damaged due to burr and dust	Attach a new scale on the place of old one	Operator's machine set time reduced	Better look and improved operator efficiency
To provide shield to avoid coolant splashing	During the operation, the coolant and grinding dust is splashed.	To provide or shield to prevent the splashing	Reduction in splashing	Saving in coolant
To provide better level for ease to operate	Difficult to operate	To provide operator friendly level	Control is easy & improve in productivity of the machine	Easy operation & control
To provide nut on column	Vibrations	Provide nut on right side of column	Vibrations stopped	Easy to work

REFERENCES:

1. C. Dahlman, Technology, globalization, and international competitiveness: challenges for developing countries in O'Connor and M Kjöller tröm (ed.), Industrial Development for the 21st Century , Hyderabad : Orient Longman, 2008, pp. 29-84.
2. N. Slack, M.Lewis, Operations strategy. England:Pearson Education Limited, 2011.
3. A. Neely. et al, "Performance measurement system design: developing and testing a process-based approach," International Journal of Operations & Production Management, vol 20(10), pp 1119-1145, 2000.
4. C. Andersson , M. Bellgran, "On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity," Journal of Manufacturing Systems, vol 35, pp144-154, 2015.
5. A.A King, M.J Lenox, Lean and Green, "An empirical examination of the relationship between lean production and environmental performance," Production and Operations Management vol 10(3), pp 244-256, 2001
6. K. Romvall, M. Wiktorsson, M. Bellgran, "Competitiveness by integrating the green perspective in production: A review presenting challenges for research and industry" Proceedings of the 20th international conference on flexible automation and intelligent manufacturing (FAIM 2010): pp. 318-325, 2010.
7. C.J Bamber, P. Castka, J.M Sharp, Y. Motara, "Cross-functional team working for overall equipment effectiveness (OEE)," Journal of Quality in Maintenance Engineering, vol. 9(3): 223-238, 2003.
8. C.J Bamber, J.M Sharp, M.T Hides, "Factors affecting successful implementation of total productive maintenance: A UK manufacturing case study perspective," Journal of Quality in Maintenance Engineering, vol. 5(3): pp. 162-181, 1999.
9. S. Nakajima, Introduction to total productive maintenance. Productivity, Cambridge: MA, 1988.
10. S. Nakajima, TPM development program: Implementing total productive maintenance. Productivity, Cambridge: MA, 1989.
11. K. Shirose, "Total Productive Maintenance: New Implementation Program in Fabrication and Assembly Industries," Japan Institute of Plant Maintenance, Tokyo, 1996.
12. T. Wireman, "Total Productive Maintenance - An American Approach. Industrial," New York, 1991.
13. T. Wireman, "Total Productive Maintenance. Industrial Press, Inc., US,2004.
14. P. Willmott, Total Productive Maintenance: The Western Way, Oxford : Butterworth-Heinemann,1994
15. M. Tajiri, F. Gotoh, TPM Implementation: A Japanese Approach. New York : McGraw-Hill, 1992
16. E.H. Hartmann, Successfully Installing TPM in a Non-Japanese Plant. Pittsburgh: Pa. TPM Press, 1992
17. I.P.S Ahuja, J.S Khamba, "Total productive maintenance: literature review and directions," International Journal of Quality and Reliability Management vol. 25(7): pp. 709-756, 2008
18. P. Jonsson, M. Lesshammar, "Evaluation and improvement of manufacturing performance measurement systems - the role of OEE," International Journal of Operations & Production Management, vol. 19(1), pp. 55-65, 1999
19. P.W. Prickett, "An integrated approach to autonomous maintenance management," Integrated Manufacturing Systems, vol. 10(4): pp. 233-243, 1999
20. Ő . Ljungberg, "Measurement of overall equipment effectiveness as a basis for TPM activities," International Journal of Operations & Production Management vol. 18(5): pp. 495-507, 1998
21. B. Dal, Dal, Ki-Y Jeong, D.T. Phillips, "Operational efficiency and effectiveness measurement," International Journal of Operations & Production Management vol. 21(11), pp. 1404-1416, 2001
22. P. Chandna, A. Chandra, "Quality tools to reduce crankshaft forging defects: An industrial case study," Journal of Industrial and Systems Engineering vol. 3(1): pp. 27-37, 2009